



Screening Evaluations for Upland Confined Disposal Facility Surface Runoff Quality

by Paul R. Schroeder, Susan E. Bailey, Trudy J. Estes, and Richard A. Price

PURPOSE: Section 404 of the Clean Water Act requires evaluation of the potential impacts of dredged material discharges from confined disposal facilities (CDFs). A joint U.S. Army Corps of Engineers (USACE) and U.S. Environmental Protection Agency (EPA) Technical Framework (USEPA/USACE 2004) provides guidance for evaluation of potential contaminant pathways to determine if controls or management actions are required. Guidance for implementation of the Technical Framework is provided in the USACE Upland Testing Manual (UTM) (USACE 2003). The UTM provides a tiered approach for performing pathway evaluations. Tier II of the UTM contains a screening methodology to determine the need for pathway testing. The screens compare screening criteria, such as water quality standards, with predictions based on bulk sediment chemistry and partitioning/bioavailability relationships.

One potential pathway of contaminant release from CDFs is surface runoff water discharged after CDF filling operations have been completed. The simplified laboratory runoff procedure (SLRP) and runoff simulator/lysimeter system (RSLS) tests are available to predict chemical releases in surface runoff for comparison to water quality criteria, and water column bioassays are available to determine potential toxicity of surface runoff (USACE 2003). This technical note provides procedures for evaluating CDF surface runoff quality at the screening level of a multi-tiered approach. The screening evaluation is based on equilibrium partitioning principles (Hill et al. 1988) and conservative application of design and operating principles for CDFs. An electronic spreadsheet program to apply the screens, when finalized, may be downloaded from the [ADDAMS/Dredged Material Models website](#).

BACKGROUND: One alternative for dredged material disposal is placement in diked confined disposal facilities (CDFs). CDFs are frequently used for placement of dredged material because they are often the most cost-effective and environmentally sound option. CDFs are often considered as an alternative for contaminated dredged material that is unsuitable for conventional disposal in open water. Possible contaminant migration pathways for CDFs include effluent discharges to surface water during filling operations, surface runoff due to precipitation, leachate into groundwater, volatilization to the atmosphere, and direct uptake by plants and animals. Each of these pathways may have its own standards and criteria defined by the water quality certification or other applicable laws and regulations. If standards or criteria are likely to be exceeded, a variety of management options or control measures may be considered.

Surface runoff is defined as the water and associated suspended and dissolved materials released from island, nearshore, or upland CDFs resulting from precipitation events on exposed dredged material and would include water discharged directly over weir structures or through filter cells or retaining dikes (USACE 2003). The quality of the surface runoff discharged from these sites

Report Documentation Page				Form Approved OMB No. 0704-0188	
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE SEP 2008		2. REPORT TYPE		3. DATES COVERED 00-00-2008 to 00-00-2008	
4. TITLE AND SUBTITLE Screening Evaluations for Upland Confined Disposal Facility Surface Runoff Quality				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory, 3909 Halls Ferry Road, Vicksburg, MS, 39180-6199				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT Same as Report (SAR)	18. NUMBER OF PAGES 13	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

is an environmental concern and is regulated as a discharge under Section 404 of the Clean Water Act and the National Environmental Policy Act (NEPA). In addition, surface runoff water quality standards may be set as a condition of the Section 401 State water quality certification.

Dredged material may be placed in CDFs by hydraulic or mechanical means. Dredged material hydraulically placed in a confined disposal area settles, with coarser particles settling near the pipe placement area in a higher elevation and finer-sized particles settling closer to the weir discharge point(s) at lower elevations. The surface runoff waters are discharged from the site over the weirs during rainfall events following dredging and filling operations. Figure 1 is a schematic of surface runoff from a CDF. The surface runoff water may contain both dissolved contaminants and suspended colloidal particles with associated (adsorbed or held by ion exchange) contaminants. A large portion of the total contaminant concentration is particle-associated, and the CDF should be designed to retain the suspended materials and provide adequate storage capacity. Procedures for engineering design of CDFs for storage and solids retention are available (USACE 1987).

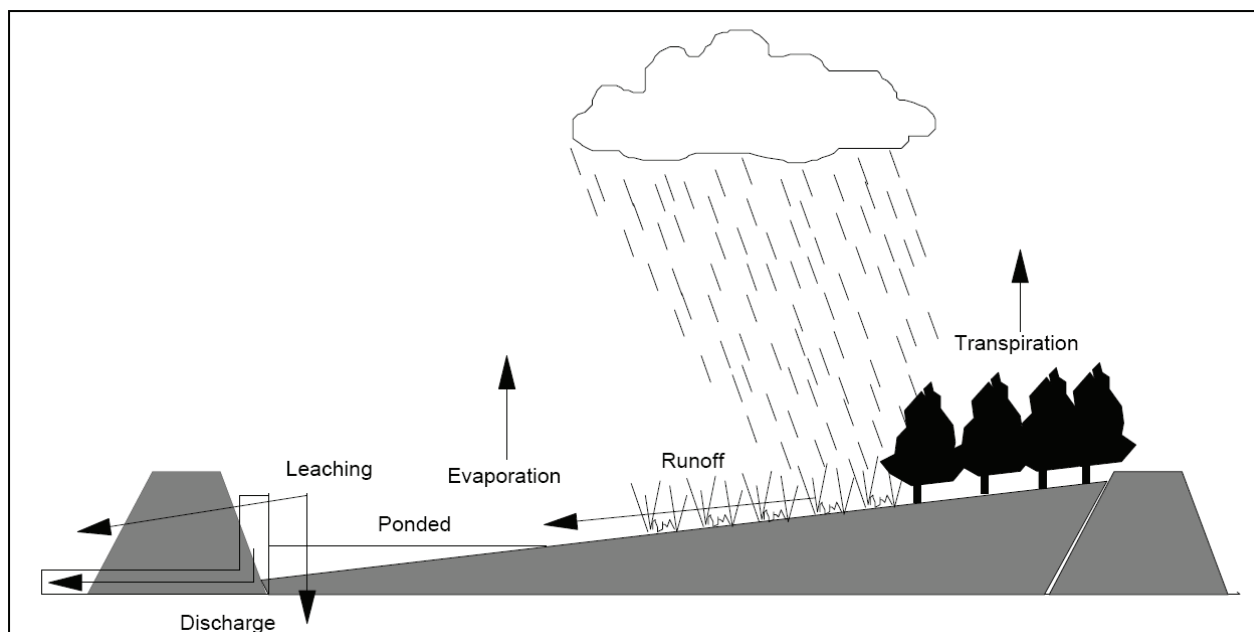


Figure 1. CDF surface runoff process (USACE 2003).

Guidance for evaluating dredged material placement under Section 404 of the Clean Water Act is provided in the Upland Testing Manual (UTM), which includes testing procedures for surface runoff quality evaluation (USACE 2003). Water column effects resulting from surface runoff are evaluated using a tiered approach generally patterned after that for discharges of effluent into open water. Surface runoff test procedures are available to predict concentrations of contaminants in the rainfall-induced surface runoff from confined disposal areas. Water column bioassays may also be conducted using the surface runoff test as a medium (USACE 2003).

The effects of mixing and dispersion must be considered in evaluating surface runoff discharges. Mixing zones (which are usually defined in terms of an allowable surface area or volume of water) are defined by the State 401 regulatory agency as a part of the Section 401 water quality

certification. The point of compliance of the surface runoff discharge is at the edge of the mixing zone.

The Simplified Laboratory Runoff Procedure (SLRP) test and the Runoff Simulator/Lysimeter System (RSLS) test are Tier III tests in the multi-tiered approach contained in the UTM. While these tests provide a reliable means to assess surface runoff, they are expensive and time-consuming. Many projects involve sediments, which have minimal potential for impact; therefore, screening procedures are needed to determine when the tests should be conducted.

BASIS OF SURFACE RUNOFF SCREENING EVALUATION: The surface runoff screening procedures presented here are based on equilibrium partitioning principles (Hill et al. 1988) and conservative application of design and operating principles for CDFs. Procedures are given for evaluating surface runoff releases from both mechanically dredged and hydraulically dredged or offloaded sediments. The evaluation utilizes site-specific data input by the user and default values for pertinent parameters to calculate a predicted runoff contaminant concentration at the weir or at the edge of the mixing zone based on bulk sediment contaminant concentrations. If the predicted runoff quality exceeds the standards at the point of compliance, additional testing and evaluations are necessary.

The same principles can be used to calculate a maximum allowable bulk sediment concentration that will result in the runoff meeting water quality standards at the point of compliance. Actual bulk sediment concentrations above the maximum allowable bulk sediment values would result in additional testing and evaluations.

Where sediments are hydraulically dredged, the surface runoff initially produced after the CDF filling operation is completed is a result of mixed and settled material from two systems initially at equilibrium (sediment/pore water and water column/suspended solids), in which the contaminants present are partitioned between the solids and the surrounding fluid. When these systems are mixed and settled in a CDF, two scenarios are theoretically possible: 1) the contaminants in the settled mixture will establish a new equilibrium between the solids and pore water, or 2) dissolved concentrations in the surface runoff will be a simple function of mixing the pore water and the rainfall runoff water. During a rainfall event, rainfall disturbs the surface dredged material and results in resuspension of solid particulates. The resulting suspension will tend to migrate toward the CDF weir.

The retention time in most CDFs is on the order of a day to a few days. Contaminant partitioning between the solid and aqueous phases in the resuspended solids is not likely to reach equilibrium due to the short contact time after resuspension and mixing during the rainfall event. Equilibrium partitioning is therefore considered to be a boundary condition for initial surface runoff quality, and a screen based on equilibrium partitioning would therefore be conservative.

The surface runoff quality screening protocol is essentially identical to effluent quality for hydraulic disposal of dredged material in a confined disposal facility and was likewise developed based on the equilibrium and mixing boundary conditions. The protocol produces two estimates of the allowable bulk sediment concentration based on two drying conditions: oxidized and unoxidized.

After the dredged material dries out and becomes oxidized, the material behaves differently than dredged material in the early stages of drying. During drying the dredged material consolidates and forms cracks in the surface of the CDF. For projects involving dredging in estuarine or marine environments, surfaces of the dredged material tend to accumulate salt as the pore water moisture evaporates from the surface, leaving any salt dissolved in the pore water on the surface of the cracks. Rainfall dissolves the salt and rinses the surface of the dredged material of accumulated salt. During the drying process many metals such as zinc, cadmium, copper, nickel, lead, and mercury are converted from poorly soluble metal sulfides formed under reduced anoxic conditions to more soluble metal sulfates and metal hydroxides. Organic contaminants become tightly adsorbed onto soil and organic particulates and mostly remain associated with suspended solids in surface runoff water. Therefore, the solids content of the surface runoff and the equilibrium partition coefficients will be different for oxidized and unoxidized conditions, which will affect the surface runoff quality.

The equilibrium partitioning calculations assume that only a fraction of the metals in the sediment is leachable. The fraction varies from metal to metal and between oxidized and unoxidized conditions. It is further assumed that contaminant concentration in the background receiving water is completely leachable and that the contaminant concentration in rainfall is negligible. In both cases, dilution occurring within the mixing zone at the point of discharge is taken into consideration in calculating the maximum allowable bulk sediment concentration.

INPUT PARAMETERS: An electronic spreadsheet program is available to apply screens to include all necessary calculations. Contaminants of concern concentrations are site-specific parameters input by the user and include the following:

- Bulk sediment concentration (q), mg/kg - the concentration of contaminants of concern in the in situ sediments.
- Background water concentration (C_B), $\mu\text{g/L}$ - the dissolved concentrations of the contaminants of concern at the point of discharge from the CDF, within the mixing zone (note that the background or receiving water and dredging site water are often the same water body).

Several default parameters are also utilized in the spreadsheet calculations. Default parameters are derived from the literature, previous or current testing, or site information and are specific to hydraulic or mechanical disposal. Default parameters can be altered for site-specific conditions where indicated. Some parameters are measured values only and must be provided by the user. Water density (ρ_w) is assumed to be 1 g/cm^3 . Properties and parameters for the surface runoff screen include the following.

- In situ sediment properties:
 - Total organic carbon (TOC), % – measured value.
 - Silt & clay fraction (SCF), % – measured value.
 - Clay fraction (CF), % – measured value.

- Effective clay content (CF_{eff}), % - calculated using the silt & clay fraction (SCF) and the clay fraction (CF).
 - Enrichment factor (EF) – calculated for hydraulically placed dredged material using CF_{eff} and assigned to be equal to 1 for mechanically placed material.
 - Specific gravity (SG) – measured or default value.
 - Dissolved organic carbon (DOC) in pore water, (mg/L) – measured value.
 - Water content (w), % – measured value.
 - Void ratio (e) – calculated using the specific gravity of the sediment (SG) and the in situ sediment water content.
 - Porosity (n_{sed}) – calculated from the in situ void ratio.
 - Solids concentration (TSS_{sed}), g/L – calculated using the porosity of the sediment (n_{sed}) and the specific gravity (SG) of the sediment.
- Surface runoff parameters:
 - Dilution within mixing zone (D) – In the present version, this pertains only to upland CDFs (assumes no dilution occurs within the CDF from ponded conditions existing prior to material placement). The dilution occurring within the mixing zone is calculated (externally to the spreadsheets) using estimates of surface runoff and receiving water flow rates and mixing zone volume.
 - Allowable background exceedance (x), % – This parameter applies when contaminant concentrations in the background or carrier water exceed water quality criteria. An acceptable, short-term exceedance of water quality criteria is defined under a regional area decision (RAD) or local area decision (LAD).
 - Unoxidized runoff solids concentration (TSS_{run}^{unox}), g/L – Default values are 20 g/L for hydraulically dredged material and 0.5 g/L for mechanically placed material.
 - Unoxidized runoff-sediment slurry porosity (n_{run}^{unox}) – calculated using the unoxidized runoff solids concentration (TSS_{run}^{unox}), the specific gravity of the sediment (SG), and the density of water (ρ_w).
 - Oxidized runoff solids concentration (TSS_{run}^{ox}), g/L – Default values are 2 g/L for hydraulically dredged material and 0.5 g/L for mechanically placed or vegetated material (Price 2002).
 - Oxidized runoff-sediment slurry porosity (n_{run}^{ox}) – calculated using the oxidized runoff solids concentration (TSS_{run}^{ox}), the specific gravity of the sediment (SG), and the density of water (ρ_w).

Chemical-specific parameters utilized in computations include octanol/water partitioning coefficient (K_{ow}), oxidized and unoxidized distribution coefficients (K_d^{ox} , K_d^{unox}), normalized oxidized and unoxidized leachable fraction (LF^{ox} , LF^{unox}), aqueous solubility, and marine or freshwater chronic water quality criteria (C_{wq}). There is also provision for user input criteria. Values for these parameters were taken from various sources, including Warren and Streng (1994), Ruiz et al. (2000), and USEPA (1998, 1999).

RUNOFF SCREENING CALCULATIONS: An electronic spreadsheet program is available to apply the screens to include all necessary calculations. The screen calculates a predicted runoff contaminant concentration for measured bulk sediment concentrations. The calculations are essentially the same as for the effluent pathway, with the equilibrium boundary condition

assumption. Values are calculated for both unoxidized and oxidized conditions (effluent screen assumes unoxidized material). The equations used in the calculations are the same for both hydraulic and mechanical filling operations and are presented below.

PREDICTED RUNOFF QUALITY CALCULATIONS: The following steps are performed to calculate the predicted runoff contaminant concentrations for both unoxidized and oxidized conditions.

Leachable Contaminant Concentration. The leachable sediment contaminant concentration is calculated from measured bulk sediment concentration and the leachable fraction for both oxidized and unoxidized conditions.

If the sediment is hydraulically placed, the leachable contaminant concentration (q_{sediment}^*) is normalized using an enrichment factor (EF) for both metals and organics and adjusted for the leachable fraction of the metals. The enrichment factor is dependent on effective clay fraction and is based on the assumption that the contaminant concentration in the upper layers of exposed sediment is somewhat greater than bulk sediment concentrations due to more rapid preferential zone settling of larger particles of the bulk slurry and subsequent enrichment of the surface layer by the slow flocculent settling of the smaller, contaminant-laden clay particles.

For mechanically placed sediment, differential settling and therefore enrichment are not likely to occur; thus the enrichment factor is typically set to 1 ($EF = 1$). However, the leachable contaminant concentration for metals must be adjusted for the leachable fraction and normalized using the silt and clay fraction because the K_d value used in subsequent equations is for a material composed only of fine-grained particles. The following equations are used.

1. Calculate the leachable contaminant concentration from the solids in the sediment, based on measured bulk sediment concentration and the leachable fraction for oxidized and unoxidized conditions. The following equations are used:

Hydraulically placed material:

$$q_{\text{sediment}}^{*i} = LF^i * q * EF \quad (1)$$

Mechanically placed material – Organics:

$$q_{\text{sediment}}^{*i} = LF^i * q \quad (2)$$

Mechanically placed material – Metals/inorganics:

$$q_{\text{sediment}}^{*i} = LF^i * \frac{q}{SCF / 100} \quad (3)$$

where

- $q_{sediment}^{*i}$ = leachable contaminant concentration in exposed dredged material at the surface of the CDF or CF_{eff} at equilibrium in the sediment for oxidized and unoxidized conditions, mg/kg
 LF^i = leachable/soluble fraction of contaminants in the CF_{eff} for oxidized and unoxidized conditions ($LF_{organics} = 1$)
 Q = measured contaminant concentration in bulk sediment, mg/kg
 EF = enrichment factor ($100/CF_{eff}$ for hydraulically placed material); (1 for mechanically placed material)
 SCF = silt/clay fraction (%)
 CF_{eff} = effective clay content (%), (clay fraction + 10% silt fraction)
 i = oxidized or unoxidized condition of material

LF is the leachable fraction of the bulk concentration in the fine-grained materials. For organic contaminants, the leachable fraction is equal to one. In the program, LF is a default parameter and values were selected from elutriate testing, field observations, and other empirical evidence. When the screen is used as a Tier II evaluation to determine the need for Tier III testing, site-specific data such as is derived from the elutriate test is often unavailable, and default values must be utilized. However, if elutriate testing results from prior evaluations are available, overriding the default values with site-specific data will improve the screening results.

Predicted Runoff Concentrations - Equilibrium Boundary Condition.

2. Calculate the leachable contaminant concentration per mass solids in the runoff slurry using the leachable contaminant concentration of the bulk sediment. If the concentration in the rainfall is not negligible, the leachable contaminant concentration should be calculated as follows:

$$q_{run}^{*i} = q_{sediment}^{*i} + \frac{(TSS_{CDF}^i - TSS_{run}^i)C_R}{TSS_{CDF}^i * TSS_{run}^i} \quad (4)$$

where

- q_{run}^{*i} = leachable contaminant concentration at equilibrium in the runoff (mass of contaminant associated with sediment solids, pore water and rain water per mass solids), mg/kg
 TSS_{CDF}^i = total suspended solids concentration in CDF surface sediment, g/L
 TSS_{run}^i = total suspended solids concentration in runoff slurry, g/L
 C_R = dissolved rain water contaminant concentration, $\mu\text{g/L}$.

3. Note however that Equation 4 is not actually used in the spreadsheet. The screening procedure assumes that the contaminant concentration in the rainfall is negligible ($C_R = 0$). Therefore, the program assumes:

$$q_{run}^{*i} = q_{sediment}^{*i} \quad (5)$$

If the user believes rainfall concentrations to be significant, then Equation 4 and the associated parameters would need to be input into the spreadsheet by the user.

4. Calculate the dissolved contaminant concentration at the weir. The following equation is used:

$$C_{run}^i = \frac{q_{run}^{*i} (1000 \mu g / mg) (1 - n_{run}^i) \rho_s}{n_{run}^i + K_d^i (1 - n_{run}^i) \rho_s} \quad (6)$$

where

- C_{run}^i = dissolved contaminant concentration in runoff slurry at the weir, $\mu g/L$
- n_{run}^i = porosity of runoff slurry for oxidized or unoxidized conditions
- ρ_s = density of solid particles, kg/L
- K_d^i = equilibrium distribution coefficient for oxidized or unoxidized conditions, L/kg

For inorganic contaminants, the K_d values were selected from literature sources, past elutriate testing, field observations and other empirical evidence. This K_d value is normalized for the silt and clay fraction. For organic contaminants (organotins, PAHs, organophosphorus pesticides, chlorinated pesticides, semivolatile organic compounds, PCBs and dioxins), K_d is calculated as follows:

$$K_d = \frac{0.617 * FOC * K_{OW}}{1 + (0.617 \times 10^{-6} DOC * K_{OW})} \quad (7)$$

where

- FOC = fraction organic carbon in the solids (TOC (%)/100)
- K_{OW} = octanol-water equilibrium partitioning coefficient
- DOC = dissolved organic carbon concentration in pore water, mg/L

Determination of Requirement for Runoff Testing Based on Maximum Predicted Runoff Concentration. Compare the largest of the predicted runoff concentrations for both boundary conditions to constituent solubility. If the maximum predicted value is greater than solubility, the default maximum runoff concentration is taken to be the constituent solubility. Calculate the predicted dissolved contaminant concentration at the mixing zone boundary considering the allowable mixing zone, background concentration, and dissolved contaminant concentration at the weir, using the predicted runoff concentration. The following equation is used:

$$C_p^i = \frac{C_{run}^i + DC_B}{D + 1} \quad (8)$$

where

- C_p^i = predicted dissolved contaminant concentration at mixing zone boundary, $\mu\text{g/L}$
D = dilution ratio available in mixing zone
 C_B = dissolved contaminant concentration of background (receiving) water, $\mu\text{g/L}$

If C_p exceeds applicable water quality criteria for the relevant oxidation condition, Tier III testing is needed.

PREDICTED ALLOWABLE SEDIMENT CALCULATIONS: The protocol can be applied with some modification to determine the allowable sediment concentration that will result in runoff meeting water quality criteria at the edge of the mixing zone. Although the detailed procedure is not presented here, a separate electronic spreadsheet program is available upon request to apply the screens in reverse order to estimate a maximum allowable sediment concentration. As with the above procedure, the allowable sediment concentration is calculated based on equilibrium partitioning and is then compared to the actual bulk sediment concentration. Ratios of actual to allowable greater than 1 indicate water quality criteria may be exceeded, and Tier III testing is needed.

VERIFICATION: The screening protocol was evaluated using field data from Black Rock Harbor, CT (Skogerboe et al. 1987) and lysimeter data from Black Rock Harbor, Everett Harbor, WA (Palermo et al. 1989), Indiana Harbor, IN (Environmental Laboratory 1987), New Bedford Harbor, MA (Skogerboe et al. 1988), Oakland Harbor, CA (Lee et al. 1993a), Santa Fe Channel, CA (Lee et al. 1993b), and Pinole Shoal and West Richmond reaches of the John F. Baldwin Ship Channel, CA (Lee et al. 1993c). The predicted surface runoff concentrations of various metals were compared with field and large-scale laboratory lysimeter measurements. The results of the comparisons for metals are shown in the following graphs (Figures 2 and 3). Ratios less than one indicate surface runoff concentrations were under-predicted, while ratios greater than one indicate over-prediction of surface runoff concentrations. The screening protocol for metals produces a conservative estimate of the field concentration (on average approximately 30 and 14 times the field values for unoxidized and oxidized conditions, respectively). For unoxidized conditions (Table 1), out of 61 metals results, the screen under-predicted the field or lysimeter runoff concentration in 7 cases, although none of those cases violated water quality criteria (thus, no false-positive results where the screening results would predict no problems, but the field testing results failed to pass water quality criteria). The screen resulted in a recommendation of additional testing for 15 unoxidized metals cases, and for 8 of those cases the actual field/lysimeter concentrations were below criteria (thus, 8 false-negative results where the screening results would predict potential problems, but the field testing results passed water quality criteria). For the 63 oxidized metals data points, there were no false-positive results out of 17 under-predictions, and 9 false-negatives out of 23 recommendations for additional testing. As such, the screening protocol provides a conservative method for predicting surface runoff concentrations for metals based on bulk sediment concentrations.

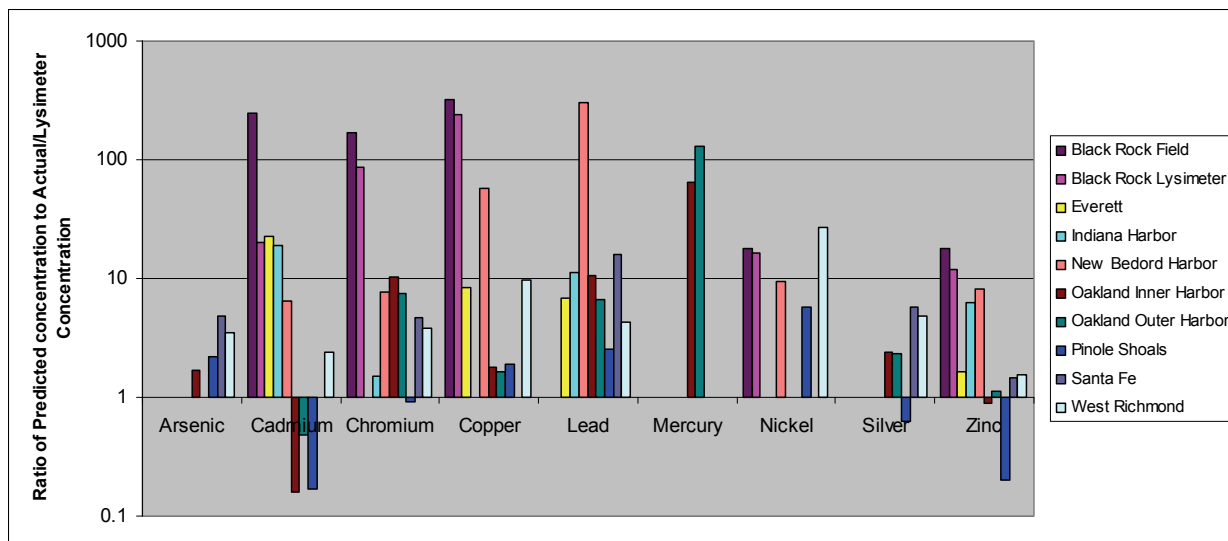


Figure 2. Ratios of predicted runoff concentrations to field or lysimeter concentrations for various sediments - metals under unoxidized conditions.

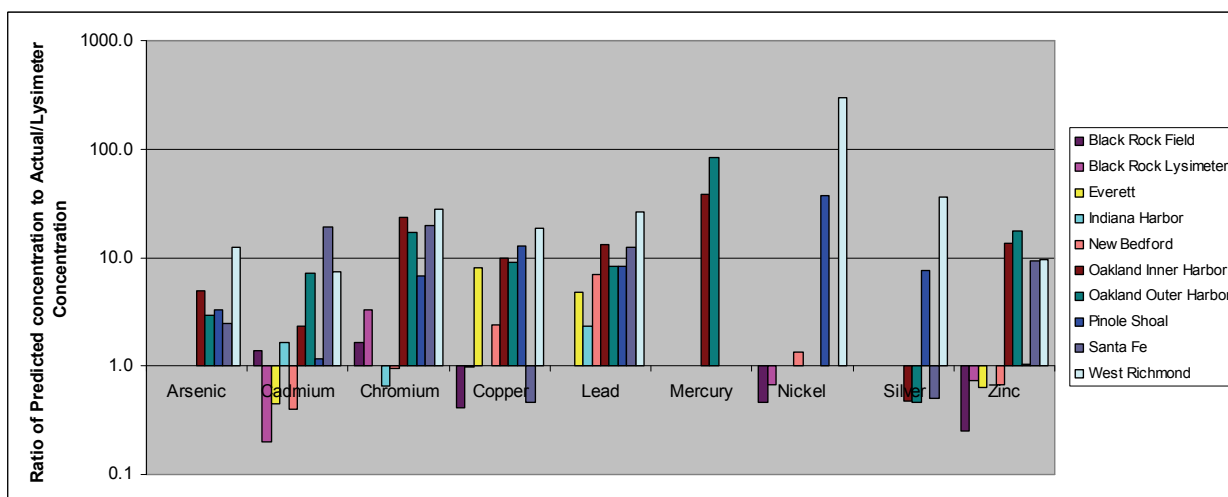


Figure 3. Ratios of predicted runoff concentrations to field or lysimeter concentrations for various sediments - metals under oxidized conditions.

Table 1. Comparison of field or lysimeter runoff concentrations to screen predictions.

Contaminant	Number of Data Points	Number of Under-Predictions	Number of False-Positive Results	Number of Cases with Additional Testing Recommended	Number of False-Negative Results
Unoxidized Conditions					
Metals	61	7	0	15	8
PAHs	39	30	0	9	4
PCBs	3	0	0	3	1
Organotins	5	3	0	0	0
Oxidized Conditions					
Metals	63	17	0	23	9
PAHs	10	6	0	2	2
PCBs	0	0	0	0	0
Organotins	5	3	0	0	0

Concentrations of organics were not reliably predicted using this screening technique. Predicted PCB aroclor concentrations for New Bedford and Indiana Harbors (unoxidized condition) were over-predictive by an average of 54 times the lysimeter concentrations and provided a false negative result in one of three cases. Tributyltin predictions ranged from 0.28 to 2.9 times the measured values for unoxidized conditions and 0.32 to 17 times measured values for oxidized conditions and generated no false-negative or false-positive results. However, concentrations of PAHs were generally under-predicted (in 77 percent and 60 percent of instances for unoxidized and oxidized conditions) as the measured lysimeter concentrations were relatively high, even above aqueous solubility in some instances. It is suspected that unfiltered solids or dissolved organic carbon and oil and grease suspended in the runoff may have contributed to the higher-than-predicted lysimeter concentrations. Overall, the screening technique provided a conservative technique for prediction of surface runoff concentrations.

SUMMARY: This technical note provides procedures for evaluating CDF surface runoff quality at the screening level of a multi-tiered approach. The screening evaluation is based on equilibrium partitioning principles and conservative application of design and operating principles for CDFs. An electronic spreadsheet program is available to apply the [screens](#).

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Schroeder, P. R., S. E. Bailey, T. J. Estes, and R. A. Price. 2008. *Screening evaluations for upland confined disposal facility surface runoff quality*. DOER Technical Notes Collection. ERDC TN-DOER-R12. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

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